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INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 5 : G21K 5/04, H01J 33/04	A1	(11) International Publication Number: WO 94/07248 (43) International Publication Date: 31 March 1994 (31.03.94)

(21) International Application Number: PCT/US93/08895

(22) International Filing Date: 21 September 1993 (21.09.93)

(30) Priority data:
07/950,530 23 September 1992 (23.09.92) US

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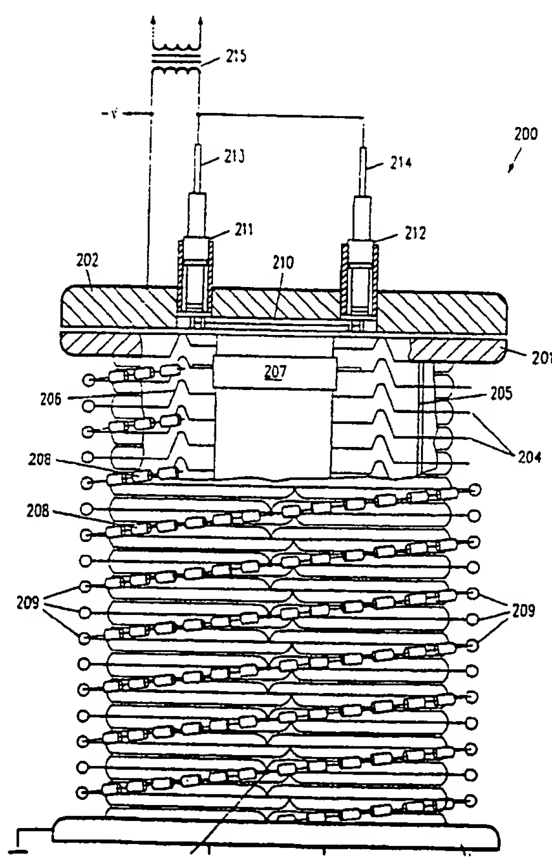
(81) Designated States: CA, JP, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).

Published
With international search report.

(54) Title: PARTICLE ACCELERATOR

(57) Abstract

An electron beam accelerator has an accelerator tube consisting essentially of metal and ceramic components which are fused directly to each other and a transmission window generally rectangular in shape when viewed in the direction of the electron beam and is convex towards the vacuum chamber with a radius of curvature which is at most twice the width of the rectangle when measured in teh absence of a pressure differential across the window. The electron beam accelerator is particularly suitable for use as a liquid material process. The preferred transmission window of the accelerator of the invention can withstand energy transfer rates of at least 1500 watts per gram of the window material to which the energy is transferred. Certain embodiments are especially suitable for irradiating fluids to higher doses or for irradiating liquids containing suspended solids or slurries. A mobile transporter enabling relocation of the liquid material processor between process sites is also described.



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PARTICLE ACCELERATOR

Technical Field of the Invention

The present invention relates to improvements in high energy particle accelerators especially for use within industrial processes for treating various materials. More particularly, the present invention relates to an improved electron beam accelerator and improved methods and apparatus for processing liquids.

Background of the Invention

Particle accelerators are employed to irradiate a wide variety of materials for several purposes. One purpose is to facilitate or aid molecular crosslinking or polymerization of plastic and/or resin materials. Other uses include sterilization of foodstuffs and medical supplies and sewage, and the destruction of toxic or polluting organic materials from water, sediments and soil.

An electron beam accelerator typically includes (i) an electron emitter, (ii) an accelerator for shaping the emitted electrons into a beam and for directing and accelerating the highly energized electron beam toward a transmission window, (iii) usually a beam scanning or deflection means and (iv) a transmission window and window mounting. A generator is provided for generating the considerable voltage difference needed to power the accelerator.

The emitter and the accelerator section, which may comprise centrally arranged dynode elements or other beam shaping means, or electrostatic or electromagnetic lenses for shaping, focusing and directing the beam, are included within a highly evacuated vacuum chamber from which air molecules have been removed so that they cannot interfere with the electron beam during the emitting, shaping, directing and accelerating processes.

The transmission window is provided at a target end of the vacuum chamber and enables the beam to pass therethrough and thereby exit the vacuum chamber. The workpiece to be irradiated by the particle beam is usually positioned outside the accelerator vacuum chamber and adjacent to the transmission window in the path of the electron beam.

As used herein, "transmission window" is a sheet of material which is substantially transparent to the particle beam impinging thereon and passing therethrough. The transmission window is mounted on a window mounting comprising a support frame which includes securing and retention means which define a window envelope.

The conventional beam transmission window, usually rectangular with filleted (that is, rounded concave) corners and generally perpendicular with respect to a longitudinal axis of the particle beam, must be sufficiently thin and of a suitable material so as not to attenuate the beam unduly from energy absorption and consequent heating. The window material must be sufficiently strong to withstand the combined stresses due to the pressure difference from typical ambient atmospheric pressure on one side thereof and high vacuum on the other and due to the heat generated by the particle beam in passing therethrough.

Conventionally, transmission window foils have typically been installed between rectangular, generally flat flanges with filleted corners. The thin window foils are typically formed of titanium or titanium alloy sheets or foils which typically range in thickness between about 0.0005 inches (0.013 mm) and 0.004 inches (0.104 mm). Much thicker stainless steel foils have been employed as transmission windows in irradiation apparatus for waste water/effluent processing.

Hitherto, accelerator sections used in accelerators for such applications have been fabricated from glass and metal components secured to one another with organic thermosetting resins, for example, epoxy resins. Although such composite tubes are quite readily fabricated, they are quite fragile and, when subjected to mechanical stresses, such as might occur during installation or in use, can and do break thereby necessitating dismantling of the accelerator and replacement of the tube. Moreover, many accelerators of this type produce, as indicated above, a highly energetic beam and consequently are very large and cannot be moved without first dismantling them. In recent years low energy accelerators (that is 1 MeV or less) using a long unscanned ribbon or curtain beam have become more commonly used at such voltages, because they are somewhat more robust and portable. However such accelerators are still quite fragile in use and cannot readily be moved without extensive dismantling. Heretofore, there has been an unsolved need for a smaller, more robust, lower particle energy, higher beam current, higher efficiency irradiation apparatus for radiation processing of materials such as

petroleum stock, potable water, effluents and other aqueous and liquid materials.

Summary of the Invention

We have found that by the use of an all inorganic accelerator section, we can provide an electron beam accelerator of outstanding ruggedness and resistance to damage in demanding onsite environments, such as chemical plants, oil refineries, pipelines and the like.

An electron beam accelerator apparatus is provided comprising:
a vacuum chamber including a transmission window;
an electron beam generator within the vacuum chamber; and
an electron beam accelerator tube, within the vacuum chamber, which accelerates and directs electrons from the generator towards and through the transmission window,
said accelerator tube consisting essentially of metal and ceramic components which are fused directly to each other. In a preferred embodiment the accelerator apparatus also comprises an electron beam scanning means.

In one aspect of this embodiment of the invention, the accelerator tube comprises a plurality of annular metal dynode rings whose centers lie on a straight line and which are joined together through ceramic separators. Preferably the dynode rings are composed of titanium or an alloy containing titanium and the separators are composed of alumina.

The transmission window is formed from a thin homogeneous foil having a predetermined thickness and having a predetermined length between a first end and a second end, and a predetermined width, when laid flat as a sheet prior to forming. The term homogeneous foil or homogeneous (transmission) window when used in this specification means that the foil or window is substantially uniform in composition and structure, that is, without welds, bonds, seams or joints. The window along at least part of its length comprising an active area is formed to have the locus of a curve in cross section along an active transverse dimension such that a radius of curvature R of at least a portion of the curve in cross section is less than twice the length of the active transverse dimension, that is, the transmission window is homogeneous and:

(i) when viewed in the direction of the electron beam, is generally rectangular in shape and;

(ii) when viewed along the longitudinal axis of the window, is convex towards the vacuum chamber with a radius of curvature which is at most twice the width of the rectangle when measured in the absence of a pressure differential across the window.

In a preferred embodiment of this aspect of the invention, the window is provided by the center section of a foil material whose peripheral portions are held between two mating flanges. The flanges include an upper flange and a removable lower flange which mounts against the upper flange. The terms "upper flange" and "lower flange" as used in this specification are to be understood and interpreted in relation to the electron beam direction, the upper flange being closer to the electron source than the lower flange. The upper flange and the lower flange together include a securing mechanism to secure the homogeneous window foil which is mounted therebetween and defines aligned openings to the interior of the chamber which have a length and an active transverse dimension. The aligned openings may or may not be coextensive. The upper flange and the lower flange further define a curved locus at each of said first and second ends along the transverse dimension. A transmission window is formed of homogeneous foil sheet material of a size sufficient to cover the aligned interior openings of the upper and lower flanges and the securing mechanism, and is of predetermined thickness. The transmission window is removably mountable between the upper flange and the lower flange such that the curved locus at each end along the active transverse dimension forms the homogeneous transmission window into a curved channel configuration having a finite radius of curvature in cross section along at least a portion of the transverse direction, the portion preferably being substantially the whole length of the active transverse dimension.

In one aspect of the above described embodiment, the particle beam accelerator further comprises a sealing gasket disposed between the transmission window and the upper flange (that is, the flange nearest the electron beam generator) and functioning as a sealing mechanism therefor.

In another aspect of the invention the active area of the transmission window prior to being mounted between the upper and the lower flanges of the accelerator housing is not substantially planar. Preferably, the transmission window of this aspect of the invention is preshaped to present a convex surface of generally elliptical shape to the vacuum chamber. The window preferably

comprises a radiation emission surface having a chemically inert anti-corrosion coating.

As still a further facet of the present invention, a liquid material processor includes a housing defining

a vacuum chamber including a transmission window;
an electron beam generator within the vacuum chamber; and
an electron beam accelerator tube, within the vacuum chamber, which accelerates and directs electrons from the generator towards and through the transmission window,
said accelerator tube consisting essentially of metal and ceramic components which are fused directly to each other. In a preferred embodiment the accelerator apparatus also comprises an electron beam scanning means. In this facet of the invention, the processor comprises a source for supplying a quantity of liquid material to the housing, a liquid material flow directing structure within the housing and external to the vacuum chamber for directing a flow of liquid material supplied from the source against an exterior surface of the transmission window in order to transfer heat from the transmission window to the liquid cooling fluid while simultaneous exposure to the particle beam modifies chemically the liquid cooling fluid, thereby resulting in processing of the liquid cooling fluid into processed liquid, and a liquid collection vessel within the housing for collecting the processed liquid.

Yet another aspect of this facet of the invention is of particular utility when the fluid material, for example, liquid material requires a dose so high that the flow rate of the fluid over the transmission window would not be rapid enough to keep the fluid material reliably in contact with the window by inertial forces alone. This aspect contemplates the provision of fluid flow directing means comprising a wall of similar shape to the transmission window but spaced apart therefrom, such that the window and the wall, in combination, define a closed channel flow path for the fluid across the transmission window. Provision of this type of fluid flow directing means would also enable flat or slightly dished transmission windows of the prior art to be used to impart higher doses of radiation efficiently to a fluid material flowing across an electron emissive surface of the transmission window external to the vacuum chamber of the accelerator apparatus. However, to withstand flux densities similar to those which the curved windows of the invention can withstand, somewhat thicker window foils would be needed for flat or slightly dished windows but in any event they would advantageously be

less than 0.5 mm thick. Thus embodiments of this aspect provide an apparatus for irradiating a fluid material comprising:

(i) a vacuum chamber including a transmission window assembly which comprises a transmission window;

(ii) an electron beam generator within the vacuum chamber; and

(iii) an electron beam accelerator tube, within the vacuum chamber,

which accelerates and directs electrons from the generator towards and through the transmission window,

said transmission window being homogeneous and being formed from foil less than 0.5 mm thick; and

(iv) a housing adjacent to an external surface of the transmission window which comprises:

a wall presenting a surface of similar shape to the external surface of the transmission window but spaced apart therefrom, such that the transmission window and the wall, in combination, define a closed channel flow path for the fluid across the transmission window.

Preferably the transmission window:

(i) when viewed in the direction of the electron beam, is generally rectangular in shape and;

(ii) when viewed along the longitudinal axis of the window, is convex towards the vacuum chamber with a radius of curvature which is at most twice the width of the rectangle when measured in the absence of a pressure differential across the window.

Yet another aspect of this facet of the invention is of particular utility when the fluid material, for example liquid material, to be modified exhibits characteristics which prevent it from flowing easily over or impinging on the window surface or contains abrasive or corrosive components which might damage the window surface. Embodiments of this aspect contemplate the use of a first substantially electron-transparent transmission window and a second substantially electron-transparent transmission window, whose facing surfaces are spaced apart to define a closed channel flow path, for window coolant fluid passing therebetween, which is separate from that of the fluid material to be modified. The latter is thus exposed to the beam of electrons that emerge from the second window after passing through it. These embodiments of the invention provide an apparatus for irradiating a fluid material comprising:

(i) a vacuum chamber including a transmission window assembly which comprises a first transmission window and a second transmission window;

the first transmission window being formed from a foil having a thickness of less than 0.5 mm; and the second transmission window,

being adjacent to an external surface of the first transmission window,

being formed from a foil having a thickness of less than 0.2 mm, and

being spaced apart from the first transmission window,

(ii) an electron beam generator within the vacuum chamber; and

(iii) an electron beam accelerator tube, within the vacuum chamber,

which accelerates and directs electrons from the generator towards and through the first transmission window and through the second transmission window;

such that the first transmission window and the second transmission window, in combination, define a closed channel flow path for a cooling fluid across at least the first transmission window.

Preferably the first transmission window:

(i) when viewed in the direction of the electron beam, is generally rectangular in shape and;

(ii) when viewed along the longitudinal axis of the window, is convex towards the vacuum chamber with a radius of curvature which is at most twice the width of the rectangle when measured in the absence of a pressure differential across the window.

In this aspect and in the following aspect of the invention both the first and the second transmission windows may be curved with similarly shaped facing surfaces. However it is preferred that, in the embodiments where the first window is curved, the second window be substantially planar. In other embodiments the first and second windows are substantially planar or slightly curved, for example, due to pressure differences across one or both windows. The phrase "external surface of the" ..." transmission window" used in this specification and claims means a surface external to the vacuum chamber of a transmission window that has another surface esposed to the vacuum of the vacuum chamber.

As a related aspect, the liquid material directing structure causes the flow of liquid material to be directed in accordance with an active transverse dimension of the transmission window. As a further related aspect, the liquid

material directing structure comprises a knife-blade edge positioned adjacent to an edge of the active transverse dimension. In one more related aspect, the knife-blade edge is adjustably positionable in order to control thickness of a liquid sheet of the liquid cooling fluid as applied to cool the transmission window while undergoing the chemical processing.

In accordance with a further facet of the present invention, a method is provided for modifying materials by exposure to an accelerated electron beam. The method comprises the steps of:

generating an electron beam within a vacuum chamber,

operating an electron beam accelerator,

which comprises an accelerator tube consisting essentially of metal and ceramic components which are fused directly to each other,

within the vacuum chamber to accelerate and direct electrons from the generator towards and through the transmission window;

passing the material through the beam emerging from the window; and

directing a cooling fluid against the exterior surface of the window.

Another aspect of the invention provides a method for modifying a material by exposure to a beam of accelerated electrons, the method comprising the steps of:

generating an electron beam within a vacuum chamber,

operating an electron beam accelerator within the vacuum chamber to accelerate and direct electrons from the generator towards and through the transmission window;

passing the material through the beam emerging from the window; and directing a cooling fluid against the exterior surface of the window;

the energy transferred from the electron beam to the window and removed by the cooling fluid being at least 1500 watts per g of the window material to which the energy is transferred.

As one aspect of this facet of the invention, the step of exposing the material to accelerated electrons of the electron beam causes chemical modification of the material.

As another aspect of this facet of the invention, a further step is provided for collecting the fluid medium and processed material after heat transfer to

the medium and simultaneous exposure of the material to the accelerated electrons.

As one more aspect of this facet of the invention, the medium itself comprises the material to be processed.

Yet another aspect of the invention provides a method for modifying a material by exposure to a beam of accelerated electrons, the method comprising the steps of:

(i) generating an electron beam within a vacuum chamber,

(ii) operating an electron beam accelerator, within the vacuum chamber, to accelerate and direct a continuous beam of electrons from the generator towards and sequentially through a first transmission window, comprising a foil having a thickness less than 0.5 mm, and through a second transmission window;

the first and second transmission window having facing surfaces that in combination define a closed channel flow path for a coolant fluid;

(iii) directing a cooling fluid along the flow path thereby defined and at least against an external surface of the first window; and

(iv) passing the material to be modified through the beam of electrons emerging from the second window.

Preferably in this aspect and in the following aspect of the invention the first transmission window is homogeneous and:

(i) when viewed in the direction of the electron beam, is generally rectangular in shape and;

(ii) when viewed along the longitudinal axis of the window, is convex towards the vacuum chamber with a radius of curvature which is at most twice the width of the rectangle when measured in the absence of a pressure differential across the window. Preferably in this aspect and in the following aspect of the invention the cooling fluid is directed against the facing surfaces of both the first transmission window and the second transmission window.

A yet further aspect of the invention provides a method for modifying a liquid material by exposure to a beam of accelerated electrons, the method comprising the steps of:

(i) generating an electron beam within a vacuum chamber,

(ii) operating an electron beam accelerator, within the vacuum chamber, to accelerate and direct a continuous beam of electrons from the generator towards and through a transmission window and into a processing chamber having a wall of similar shape to but spaced apart from the transmission

window, such that the window and the wall, in combination, define a closed channel flow path for the liquid material through the processing chamber and across the transmission window;

the transmission window having a thickness of less than 0.5 mm; and

(iii) passing the liquid material along the flow path and through the beam of electrons emerging from the window.

These and other objects, advantages, aspects and features of the present invention will be more fully understood and appreciated upon consideration of the following detailed description of a preferred embodiment, presented in conjunction with the accompanying drawings.

Brief Description of the Drawing(s)

In the Drawings:

Fig. 1 is a somewhat diagrammatic view in elevation of the structure of a preferred embodiment of the beam focussing and directing tube section, showing it in relation to an electron gun assembly.

Fig. 2a is a magnified view of a portion of figure 1 showing structural features of the metal/ceramic beam focussing and directing tube section.

Fig. 2b is a plan view of a dynode ring showing the details of its structure.

Fig. 2c is an enlarged detailed view of a portion of the structure shown in figure 2b.

Fig. 3 is a view of a preferred window assembly for use in the electron beam accelerator of the invention.

Fig. 4 is a view of a preferred embodiment of the transmission window for the electron beam accelerator apparatus of the invention.

Fig. 4a is a view of a preferred embodiment of the transmission window for the electron beam accelerator apparatus of the invention for use in irradiating a solid strand or sheet workpiece or a liquid.

Fig 5 is a diagrammatic side view in section and elevation of a transportable environmental liquid processing system embodying principles of the present invention.

Fig. 6 is a somewhat diagrammatic view in transverse cross section of a curved transmission window of the invention having fluid flow directing means comprising a wall of similar shape to but spaced apart from the

transmission window, such that the window and the fluid guiding means, in combination, define a closed channel flow path for the fluid across the transmission window.

Fig. 7 is a somewhat diagrammatic view in transverse section of a curved transmission window of the invention, wherein the cooling fluid flows across the transmission window as a separate stream from the liquid material being processed.

Figs. 8a and 8b are somewhat diagrammatic views in transverse cross section of double transmission windows of the invention substantially transparent to high energy particles. Fig. 8b is a view of a section of the double windows on a larger scale showing that both windows have substantially the same curvature.

Figs. 9a and 9b are somewhat diagrammatic views in transverse cross section of double transmission windows of the invention substantially transparent to high energy particles. Fig. 9b is a view of a section of the double windows on a larger scale showing that first window is curved and the second window is substantially planar.

Description of the Preferred Embodiments

Fig. 1 depicts an accelerator unit section, which acts as a beam focussing and directing unit for the electron beam accelerator of the invention. The accelerator unit 200 includes an upper flange 201 which mates to the filament flange 202 and a lower flange 203 which mounts to an upper flange of an extension tube (not shown) or to a further accelerator tube section. A series of e.g. 18 annular metal dynode rings 204, fused into an assembly with ceramic tube separators 205 (shown in greater detail in the enlarged view Fig. 2a) are positioned between the flanges 201 and 203 in vacuum sealing relation therewith. Each dynode ring 204 includes an inner annular cap portion 206. The box shaped focus element 207 is optional, is positioned only within the accelerator unit section nearest to the filament flange, and is attached to a selected one of the dynode rings in order to be at its potential relative to the negative high voltage and chassis ground. In a preferred embodiment the interior annular cup shaped portion of each dynode is secured to the outer portion thereof by suitable mechanical interlocking fasteners and may be readily detached therefrom (e.g. for cleaning) and removed from the accelerator unit section.

The voltage divider network 208 is formed of a series of high volume (10 megohm, 2 watt carbon composition) resistors which are spiralled around the dynode rings 204. Some of the resistors of the network 208 are intentionally omitted in Fig. 1 for clarity. The rings 204 have tap points 209 which provide a predetermined voltage connection from the resistance network 208 to each ring 204. Thus, as the rings 204 extend from the top flange 201 to the bottom flange 203, the voltage applied to each particular ring is dependent upon the tap location and ranges between the minus high voltage applied to one or both of the filament pair and the ground potential of the exit window.

The electron emitter structure 210 includes two holes defined through a central region of the flange 202 and they receive two electrical feedthrough insulator fittings 211 and 212 which pass electrical conductors 213 and 214 leading from the secondary of a toroidal transformer 215 to the emitters (not shown). Preferably the emitter structure contains two filament emitters, disposed parallel to each other. They are either energized one at a time, the other being used as a spare, or both are energized at the same time, with the current in one travelling in the opposite direction to that in the other, in order to cancel alternating current components of the filament current source. In operation, the beam of electrons 221 is accelerated down the tube evacuated core and exits towards a transmission window (not shown).

Fig. 2a illustrates a sectional view of a portion of the accelerator unit section 200. One part of the preferred dynode assembly is a removable spark gap component 216 installed circumferentially about the fixed portion of the dynode ring 204. The fixed dynode ring is integral to the vacuum envelope and heat bonded to the ceramic tube sections 205. Each adjacent pair of dynode spark gap components comprises a spark gap 217 as well as mechanical supports and electrical terminations for the resistor assemblies 208 of Fig. 1.

Another part of the dynode ring 204 is the interior removable cupped annular section 218. The cupped section of adjacent annular pieces nest together to eliminate any line of sight paths between the ceramic components 205 and the centrally located beam transmission region. The exclusion of line of sight paths is necessary to reduce or eliminate the possibility that charged electrons from the beam transmission region could migrate out of the central region of the tube and settle upon the insulating surfaces of the ceramic dynode ring separators eventually causing voltage breakdown to occur across the insulator.

Fig. 2b is a plane view of a cupped annular section and fixed portion of a dynode ring further illustrating the interlocking relationships therebetween. Fig. 2c shows the details of the interlock design. The cupped annular section can be removed by rotating the interior of the annulus slightly to align the tabs 219 with a plurality of indents 220 in the fixed portion of the dynode ring 204 shown in figure 2b and 2c. Thus, the cupped annular sections, resistor assemblies and spark gap components may be readily removed from within the vacuum envelope assembly and each component may be cleaned as necessary with solvents, followed, if desired, by heating in an oven to restore it substantially to its original condition.

Figure 3 illustrates an improved transmission window assembly configuration 10, which can advantageously be used in conjunction with the accelerator of Fig. 1 and which reduces the value of the transverse stress in the window foil material to a much lower level by reducing the radius of curvature over that of a nominally flat window configuration. The foil window 14 is formed into an elongated, generally U-shaped channel structure having a radius of curvature R_X of the channel portion which radius is preferably much smaller than previously existing in conventional flat window configurations of the prior art in which any radius of curvature resulted from imposition of a pressure differential between the ambient air outside the window and the vacuum inside the window once the window was installed in the accelerator. The foil window 14 may be a preform or it may be formed by following contour-forming peripheral surfaces of a window mounting structure. In the presently preferred form shown in Fig. 3, the foil window 14 is mounted between an upper flange structure 16 connected to or forming a part of the housing 12 and a detachable lower flange structure 18. A polymeric or metal 0-ring gasket 20 provides a suitable vacuum seal between the foil window 14 and facing surfaces of the upper flange 16. A continuous loop of wire having a diameter of approximately 10 mils (0.25 mm) and formed of a suitable metal, such as tin, is presently preferred for providing a durable 0-ring gasket 20.

A series of screws 22 pass through openings 24 in the lower flange and engage threaded holes 26 formed in the upper flange 16 in order to securely affix and seal the window 14 to the housing 12. The flanges 16 and 18 and associated structural elements described hereinabove may be formed as an assembly for retrofitting a conventional electron beam accelerator in order to achieve the advantages realized by practice of the principles of the present invention. Alternatively, the flanges 16 and 18 may be parts of a electron

accelerator, such as the accelerator unit 200, which is specially designed to make practical and effective use of the present invention. A preferred way of making the window mounting flanges, when used to conform the window into the desired curved shape is by electro-dynamic machining (EDM). Window materials useful in this invention include but are not limited to aluminum, titanium, beryllium and other materials such as organic polymers or polymer composites, such as metal coated polymers, for example.

The arrangement illustrated in Fig. 3 enables ready and efficient replacement of the transmission window 14 and provides access to the interior vacuum chamber 21 defined by the housing 12. Contour-forming peripheral surfaces of the upper and lower flanges 16 and 18 of this arrangement guide and direct the transmission window 14 into an elongated, curved window structure, which, for the same material thickness, is considerably stronger than the substantially flat transmission window structures employed in the prior art.

Significant improvements in window cooling efficiency may also be realized, since forced cooling fluid (gas, mist or liquid) may now be directed specifically along the surface of the curved window 14 flowing against and guided by the curvature. As shown in Fig. 4, a knife-blade edge nozzle arrangement 28 is formed in the lower flange 18 along one edge of the curved window 14 and directs cooling fluid flow 29 from a passage 30 directly against the ambient air side of the window 14 along its entire area in a direction transverse to the longitudinal axis along which the product strand 11a moves, as denoted by the arrows drawn adjacent to the window 14 in Fig. 4. (As also shown in Fig. 4, inside edges 17 of the upper flange structure 16 may be slightly curved to provide a forming surface for curving the window 14, as desired.) In this embodiment, the sheet of cooling fluid should enter the processing chamber tangential to the surface of curvature of the window 14 at the region of entry. If the sheet is formed and directed too shallowly away from the window, there will be dead air space adjacent to the window 14. If the sheet is formed and directed too steeply toward the window, excessive turbulence of the cooling fluid results.

A fluid cooled base beam-absorption structure 33 having deep cavities 35 is provided below the strand 11a to absorb any stray remnants of the beam 13a emitted from an electron emitter 15 in the swept and converged ribbon beam generator 10'.

The structures 10' and 10 shown in Figs. 4 and 4a manifest an improved angle of incidence for, and radial acceleration of, the cooling fluid stream 29 relative to the window 14 which has a beneficial effect of reducing the boundary layer (which had been a limiting factor in cooling efficiency in prior art flat window configurations). Improved cooling of the transmission window enables use of even higher accelerator power levels, since the radiation flux and hence the window power loading may be increased with increased cooling efficiency.

Fig. 4a shows a more structurally detailed view of a preferred arrangement for directing the cooling stream 29 against the window 14 in the accelerator 10, as applied in a process for irradiating a sheet workpiece 11b, moving in a direction relative to the window 14, with an electron beam 13 as depicted in the Fig. 3 diagrammatic view.

Windows 14 of the configuration shown in Figs. 4 and 4a are best cooled by causing high velocity cooling fluid (e.g. air) to flow over the surface thereof in a direction which is transverse to the axial direction of product strand flow. In this manner, the short air cooling path and radius yield maximum air velocity while minimizing dispersion and volume flow. When this cooling method is practiced within the structure depicted in Figs. 4 and 4a, the cooling air has a minimal effect upon the temperature of the product strand passing through the window volume (irradiation zone) along the radial axis of the curved window 14. The cooling air stream 29 may transport a liquid agent, such as a water mist to the outside surface of the window 14, so that the cooling liquid evaporates in proximity of the window, thereby absorbing the heat of vaporization to achieve additional heat transfer and cooling of the heated window.

Evaporation of the cooling liquid at the window surface also results in a volume expansion of cooling gas and resulting turbulence which breaks up surface boundary layers which may otherwise form and inhibit cooling efficiency. A nozzle arrangement 28 may be employed to inject water or other liquid, solid or particulate material to be processed by exposure to the electron beam, onto the airstream in the airflow path 30 and thereby be carried into direct proximity of the surface of the window 14.

Alternatively, droplets of a fluid material may be sprayed directly on to the window by a suitable nozzle structure. In this alternative approach, the nozzle structure causes a "cloudburst" of material as fine droplets and directs this mist against the transmission window. This spraying technique would

also increase the capacity of a prior art flat transmission window to withstand very high electron fluxes passing therethrough. Thus the windows of this invention can easily handle energy transfer rates from the electron beam to the window of at least 1000 watts/gram of the window material to which the energy is transferred, for example 1500 watts/gram. More preferably, windows of the invention withstand energy transfer rates thereto of at least 2000 watts/gram, for example 2500 watts/gram.

In certain circumstances the liquid material to be processed requires a relatively high radiation dosage during but one pass over the window. This need can reduce the liquid flow rate to such an extent that the unsupported liquid no longer reliably covers the whole surface of the active area of the window. In such circumstances, the liquid may be constrained to remain in contact with the window by provision of a liquid guiding means, for example a wall, of similar shape to, but spaced apart from, the transmission window such that the window and the liquid guiding means define the flow path taken by the liquid 223 over the window as depicted in Fig. 6. Fig. 6 shows a window assembly generally similar to that shown in Fig. 4a but with a liquid guiding means in the form of a lower wall 221 whose surface 222, facing the transmission window 14, is substantially identical in shape to the outer surface of the transmission window. Preferably, the spacing between the window and the liquid retaining means is such that at least 65 %, for example, 75% of the energy of the particles exiting the window is absorbed in the liquid. More preferably, the spacing between the window and the facing surface of the liquid guiding means is such that at least 80%, for example, 85% of the energy of the particles exiting the window is absorbed in the liquid. The liquid guiding means comprises a surface facing the surface of the window in contact with the liquid to be processed. Advantageously at least a portion of the surfaces of the window and the liquid guiding means facing one another form concentric semi-cylinders. The assembly may provide means for inducing turbulent or mixing flow in the liquid passing through the flow path defined by the window and the liquid guiding means. This may take the form of baffles or similar means for inducing mixing flow. In some instances it is found that the simple use of a bent or twisted wire lying across the direction of liquid flow, placed just after the exit for the liquid from the liquid feed structure 224, provides adequate mixing. The advantage of inducing mixing flow is that it enables use of a deeper channel (that is, a larger spacing between the window and the liquid guiding means) enabling substantially all if not all of the incident electrons to

be absorbed in the liquid, while ensuring that every part of the liquid receives substantially the same total radiation dose in passing across the transmission window.

The wall may be made of any suitable material, for example a metal, which is compatible with the other materials of the housing. There is some advantage to using a metal of high atomic weight which will tend to reflect any incident electrons back into the fluid material being modified. However the gain in efficiency therefrom is normally not large and better improvements might be expected from increasing the spacing between the window and the wall and increasing turbulence in the fluid material being modified as it passes through the electron beam. The wall may be cooled by the fluid material being modified by the electron beam. If it is desired that the fluid material being modified be kept cooling then cooling channels may be incorporated into the liquid guiding means.

Yet other embodiments, of particular utility when the fluid material to be processed exhibits characteristics (such as high viscosity) which prevent it from flowing over or impinging on the window surface or when the substrate fluid to be processed contains abrasive or corrosive components which might damage the window surface, contemplates the separation of the function of window cooling and fluid processing. In its simplest form the embodiment is shown in Fig. 7a, which shows a structurally detailed view of a preferred arrangement for directing the cooling fluid 29 against the window 14 in the accelerator section 10, as applied to a process for irradiating a fluid to be modified 230, flowing in a transverse direction relative to the window 14, with an electron beam 13. The cooling fluid is collected in a receiver 231 for separate disposal or it may be allowed to mingle with fluid that has been processed by the electron beam. In circumstances where it is essential that the cooling fluid be separated completely from the fluid material to be modified at least until processing has been completed, it is advantageous to use a first and a second substantially particle-transparent window, whose facing surfaces are spaced apart to define a closed channel flow path for window coolant fluid 29 passing therebetween as shown in Figs. 8a and 9a. The particle beam passes through the primary (first) particle transmission window 14, the cooling fluid 29 and the secondary (second) particle transmission window 232 in Fig. 8a, 233 in Fig. 9a before impinging upon the fluid material to be modified 230 (in both Figs. 8a and 9a). Fig. 8b shows in more detail the secondary window 232 of Fig. 8a which has a first surface 234 facing the first particle transmission

window and a second surface, 236 facing an irradiation chamber before impinging on the fluid to be treated. Fig. 9b shows in more detail the secondary window 233 of Fig. 9a which has a first surface 235 facing the first particle transmission window and a second surface, 237, facing an irradiation chamber before impinging on the fluid to be treated. The first and second particle transmission windows are spaced apart to define a fluid closed channel flow path 238 in Fig. 8b, 239 in Fig.9b, through which a coolant fluid may pass to cool at least the first window. Preferably, both first and second windows are cooled by the coolant fluid passing therebetween. The particle beam on exiting the second particle transmission window passes into the irradiation chamber which is generally of conventional design. If the substrate fluid for irradiation is suitably compatible with the second window it may be passed over the surface of the second window to optimize absorption of the particulate radiation. Otherwise the substrate fluid to be processed may be presented to the electron radiation as a weir, a falling curtain or an upwelling substrate fluid.

In Fig. 8b the first and second windows have facing surfaces 240 and 234 respectively, which are substantially identical in shape. In Fig. 9b the facing surface 241 of the first window is curved and the facing surface 235 of the second window is substantially planar. The cooling fluid may be a gas, a mixture of a gas and a liquid, or a liquid. The cooling fluid exiting the flow path may be mingled with the substrate fluid prior to or after the substrate fluid has been irradiated or it may be maintained totally separate from the substrate fluid. In these embodiments it is, of course, very desirable that energy losses in the two windows and the cooling fluid be kept to a minimum. With a design utilizing, for example, a first and a second titanium window, each of thickness 1.5 mils (0.04 mm), an incident electron beam of energy 1.5 Mev will lose 60 kev passing therethrough. If the accelerator beam current is, say, 50 ma, the total power dissipated in the windows is 3 Kw. For a 40 C rise in temperature only 17 gallons (64.5 liters) per hour of cooling water would be required. At this level such water cooling could be readily applied in the form of a mist or cloudburst suspended in a flow of gas. Of course, if evaporative cooling with water is used, much less water would be required. Thus the energy losses due to energy absorption in the windows and the cooling fluid could be kept to a very low level using these embodiments of the invention. The cooling fluid would, of course, exert a pressure on the first and second window in flowing through the closed channel flow path. That on the first window

would not significantly change its shape. However, certain configurations of the second window through which the particle beam exits into a processing chamber (for example that shown in Fig. 8a) may in some circumstances require a somewhat higher fluid pressure to be imposed in the processing chamber than that which exists within the closed channel flow path defined by the first and second windows to maintain the shape of the second window. This could be achieved by pressurizing the processing chamber or by reducing the pressure in the flow path, for example by sucking the cooling fluid through the flow path for the window coolant fluid or by using a combination of pressure on the coolant inlet and suction on the coolant outlet. The second window shown in Fig. 9a would be able to maintain its shape even if the flow path was at a somewhat higher pressure than that in the processing chamber.

It is, of course, advantageous to deposit as high a fraction of the energy of the electron beam passing down the accelerator section in a substrate, for example a liquid material, as possible. By the use of these embodiments of the invention, the first and second window may be selected to be very thin and the coolant fluid may be a gas, for example air, advantageously carrying a cloudburst or mist of cooling liquid, for example, water as mentioned hereinabove. As a result, the attenuation of an electron beam passing through the first transmission window the flow path means and the second transmission window can be advantageously made to be very small, for example, less than 35%. Preferably the attenuation of the electron beam energy caused by passing through the first transmission window, the flow path means and the second transmission window is less than 25%. More preferably the attenuation of the energy of the electron beam caused by passing through the first transmission window, the flow path means and the second transmission window is less than 20%. Most preferably the attenuation of the energy of the electron beam caused by passing through the first transmission window, the flow path means and the second transmission window is less than 15%.

Radiation Processing of Window Cooling Material

The techniques heretofore employed have typically presented a liquid sheet or "waterfall" in front of, but spaced away from, the electron beam. Conventional wisdom associated with these techniques has been to employ very highly energetic electron beam sources (e.g. 1-3 MeV) in order to obtain

sufficient electron penetration. In order to process usefully large quantities, high beam currents, such as 50 milliamperes or more have also been proposed. High energy and high beam currents require very expensive voltage generation and beam forming apparatus. In the present invention these limitations have been overcome.

For the processing of materials, such as the irradiation of an aqueous solution with toxic solutes for the purpose of reduction of the toxic materials to less toxic or non-toxic forms, the window cooling air may carry or be in part or entirely replaced with a fluid stream or cloudburst of mist carrying material to be processed by exposure to the energetic electron beam. Thus, if it is desired to facilitate a radiation initiated reaction between two separate phases such as a liquid and a gas, the liquid may be sprayed or injected into the gas stream impinging on the window or a fluid stream with bubbles of the gas dispersed therein may be directed against the window. The liquid may also be sprayed directly onto the window as fine droplets in an atmosphere of the gaseous coreactant. While a liquid medium is presently most preferred as a carrier medium for carrying (or comprising) the material to be processed, it is clear that particulates and other materials to be processed may be injected into a fluid stream provided for cooling the transmission window.

The dimensions of the exit nozzle arrangement, i.e. cooling fluid nozzle opening 28 of Fig. 4 can be spaced so as to establish that the maximum stream thickness flowing over the window is appropriate for the penetration depth of the energetic electron beam.

Beam window cooling carried out with a liquid component is much more effective than air cooling and therefore permits much higher beam flux through the window. With a very high power beam, processing of very large amounts of material within a liquid medium or carrier may be achieved economically with a relatively low electron energy. Also, by employing a thin sheet of liquid-carried material to draw heat away from the transmission window, a thicker window may be employed. For example, a window formed of 4 mil (0.1 mm) thick foil may be advantageously employed in the liquid materials process. While about 20 kilovolts per mil (200 kilovolts per mm) is lost to heating in the window foil, this heat is advantageously transferred to the liquid material to be processed. At the same time, a more durable transmission window structure is realized by virtue of the increased thickness of the window material. Since liquid has a much greater heat capacity, and since the window is being cooled by the liquid, rather than by airflow, a partial

vacuum may be pulled across the liquid side of the window which further reduces stresses in the window foil and adds robustness and longevity to the window and greater economy to the overall liquid process. Thus, as the heat capacity of the cooling fluid increases, the useful thickness of the thin window foil may likewise be increased.

In applications of liquid irradiation and processing systems of the invention especially those involving exposure of the window to chemically hostile conditions, for example, high temperature liquids or corrosive fluids, it is especially advantageous to coat that side of the window in contact with the liquid or fluid to be processed with a chemically inert or anticorrosion heat resistant coating. Such coatings include thin layers of inert metals such as gold and the noble metals, nickel and the like; and abrasion resistant ceramic and or other oxide layers, for example, anodized surface coats and the like.

A self contained, transportable fluid process system 160 using the electron beam accelerator of the invention is illustrated in Fig. 5. Therein, a conventional tractor 162 and semi-trailer contain a liquid processor system 164, power supply 166 and operator console 168. The diesel engine of the tractor 162 may be used to power a generator to supply primary operating power for the power supply 166, or a separate generator may be provided. Hoses 170 and 172 respectively provide an inlet and outlet for material to be processed and its carrier fluid medium.

The transportable system 160 may be made to be very rugged, and safe, with necessary radiation shielding, and it may also be made to be used without direct human operator supervision and control. The system 160 may thus be taken to and used in oil fields for crude oil viscosity reduction and local cracking to produce refined products for field use. It may be used to lower the hydraulic horsepower required for pumping through pipelines. It may be taken to and advantageously employed to reduce or eliminate toxic contaminants in waste streams or in potable water supplies.

In this embodiment of the invention, the electron emitter is preferably an elongated electron beam emitter. The electron accelerator comprises an all inorganic ion beam focussing and directing structure, for example, a metal and ceramic ion acceleration tube assembly comprising tube sections formed of ceramic and metal, for example, alumina ceramic and titanium components conventionally bonded together by heat, pressure and suitable fluxes, and containing internal electrodes. These sections may be bolted together using metal gasket seals (for example, aluminum, copper, or tin wire

seals) between the component sections. A particular advantage of such structures is that, should a catastrophic condition occur, such as a beam window implosion, the tube assembly can be disassembled quickly and the components cleaned and baked at a high temperature, that is up to 200 C, without harm to the components. Preferably the internal electrodes are demountable to facilitate cleaning of the components and electrodes. An especially preferred acceleration tube assembly is one intended for ion acceleration and is manufactured by National Electrostatics Corporation.

Example 1: Removal of Contaminants from Water

Water containing 0.1 to 0.3% of various textile dyes is irradiated using a liquid processor, employing the electron beam accelerator of the invention and a transmission window similar to Fig. 4a, a liquid flow rate of about 1000 gallons an hour (3800 liters per hour) and at three minute intervals. Electron beam current is 6 mA at 400kV. The color of the samples is removed after doses up to 150 kGy.

In similar experiments, water samples containing trace amounts (up to 50 micrograms per liter) of methylene chloride, chloroform, carbon tetrachloride, 1, 1, 1-trichloroethane, trichloroethylene and tetrachloroethylene are irradiated to a dose of less than 10kGy, resulting in essentially complete removal of the contaminants. Similar results are obtained with bromodichloromethane, dibromochloromethane, bromoform, trans-1, 2-dichloroethene, cis-1, 2-dichloroethene, 1, 1-dichloroethene, 1, 2-dichloroethane, 1, 1, 2, 2-tetrachloroethane, hexachloroethane, hexachloro-1, 3-butadiene, vinyl chloride, benzene, toluene, ethylbenzene, o-xylene, m-xylene, p-xylene, chlorobenzene, 1, 2-dichlorobenzene, 1, 3-dichlorobenzene, 1, 4-dichlorobenzene, dieldrin, phenol, o-cresol, m-cresol, p-cresol, polychlorinated benzenes, polychlorinated biphenyls, dioxins, chlorine containing dioxins, bromine containing dioxins, brominated benzenes, brominated biphenyls, aromatic ethers and aromatic polyethers. Thus the processor and the process of the invention can be used to remove toxic or polluting materials comprising one or more of aliphatic, alkyl-aryl, aryl compounds and organic dyes, each of which independently comprises one or more hydroxyl, carbonyl, carboxyl, thiol, mercaptan or other sulfur-containing moiety, amino, imino, amide, imide, nitro, nitroso or halogen groups, such as -F, -Cl, -Br and -I, from water or other liquids such as waste streams.

Example 2: Determination of Window Robustness

A test is performed to determine the robustness of a liquid cooled window. The window is 0.001 inch thick (0.025 mm), homogeneous, and composed of a titanium alloy (3Al 2.5V), 12 inches (30.5 cm) wide. The locus of a curve in cross section along an active transverse dimension of the active area of the window has a radius of curvature of 1.75 inches (4.45 cm). The active transverse dimension of the window is 2.94 inches (7.5 cm). The flow rate over the window is approximately 1000 gph (3800 liters per hour).

To realistically simulate the kind of window power loading expected with a high power beam system, the beam scan is turned off leaving the beam as a spot on the window having approximately 75% of the beam power concentrated in an area of 0.75 square inches (4.8 square cm). The beam is operated for about 20 minutes beginning with low power and gradually increasing up to a maximum of 5.2 kW (13mA at 400kV). This leads to a window power loading (the energy transferred from the electron beam to the window and removed by the cooling fluid) of nearly 350 watts/sq. inch (55 watts per sq. cm). After the test, the window does show some minor discoloration in the very highest flux area (probably well over 500 watts/sq. inch (78 watts/sq cm)) suggesting that for these liquid flow conditions (mixed turbulent and laminar flows) an upper limit may have been approached. For this window, 350 watts/sq. inch (55 watts/sq. cm) corresponds to an energy transfer to the window of over 3 kw per gram of the window material to which the energy is transferred, which the window withstands easily without any sign of mechanical failure.

The preferred electron beam accelerators of this invention are of the type commonly described as DC accelerators which, in operation, use a relatively constant DC potential to accelerate electrons continuously emitted from the generator. Thus, in this type of apparatus, the electron beam current is continuous.

In a preferred embodiment, a radius of curvature of the window within the rectangle, measured along the width of the rectangle, does not deviate from the average radius of curvature therein by more than 5%. Preferably a radius of curvature of the window within the rectangle, measured along the width of the rectangle, does not deviate from the average radius of curvature therein by more than 3%. More preferably, a radius of curvature of the window within

the rectangle, measured along the width of the rectangle, does not deviate from the average radius of curvature therein by more than 1%.

Claims

1. A apparatus for irradiating a substrate comprising:
a vacuum chamber including a transmission window;
an electron beam generator within the vacuum chamber; and
an electron beam accelerator tube, within the vacuum chamber, which accelerates and directs electrons from the generator towards and through the transmission window,
said accelerator tube consisting essentially of metal and ceramic components which are fused directly to each other; and
said transmission window being homogeneous and;
   (i) when viewed in the direction of the electron beam, being generally rectangular in shape and;
   (ii) when viewed along the longitudinal axis of the window, being convex towards the vacuum chamber with a radius of curvature which is at most twice the width of the rectangle when measured in the absence of a pressure differential across the window.

2. Apparatus according to claim 1, also comprising an electron beam scanning means.

3. Apparatus according to claim 2, wherein the accelerator tube comprises a plurality of annular metal dynode rings whose centers lie on a straight line and which are joined together through ceramic separators.

4. Apparatus according to claim 3, wherein the dynode rings are composed of titanium or an alloy containing titanium and the separators are composed of alumina.

5. Apparatus according to claim 1, wherein the window comprises a radiation emission surface having a chemically inert anti-corrosion coating.

6. Apparatus according to claim 5, wherein the chemically inert anti-corrosion coating comprises a chemically inert metal, oxide or ceramic.

7. Apparatus according to claim 1, wherein the window is provided by the center section of a foil material whose peripheral portions are held between two mating flanges.

8. A method for modifying a material by exposure to a beam of accelerated electrons, the method comprising the steps of:

generating an electron beam within a vacuum chamber,

operating an electron beam accelerator,

which comprises an accelerator tube consisting essentially of metal and ceramic components which are fused directly to each other,

within the vacuum chamber to accelerate and direct electrons from the generator towards and through the transmission window;

passing the material through the beam emerging from the window; and directing a cooling fluid against the exterior surface of the window.

9. A method for modifying a material by exposure to a beam of accelerated electrons, the method comprising the steps of:

generating an electron beam within a vacuum chamber,

operating an electron beam accelerator within the vacuum chamber to accelerate and direct electrons from the generator towards and through the transmission window;

passing the material through the beam emerging from the window; and directing a cooling fluid against the exterior surface of the window;

the energy transferred from the electron beam to the window and removed by the cooling fluid being at least 1500 watts per gram of the window material to which the energy is transferred.

10. A method according to claim 8 or 9, wherein the cooling fluid comprises droplets of a cooling liquid.

11. A method according to claims 8, 9 or 10, wherein the cooling fluid medium comprises the material to be modified.

12. A method according to claim 8, 9, 10 or 11 wherein the material to be modified comprises a liquid.

13. A method according to claim 12, wherein the material to be modified comprises water.

14. A method according to any one of claims 8 to 13, wherein the material to be modified also comprises an organic material.

15. A method according to any one of claims 8 to 13, wherein the material to be modified comprises at least one of aliphatic, alkyl-aryl or aryl compound containing at least one hydroxyl, carbonyl, carboxyl, thiol, mercaptan or other sulfur-containing moiety, amino, imino, amide, imide, nitro, nitroso or halogen group.

16. A method according to claim 15, wherein the material to be modified comprises an organic dye.

17. A method according to any one of claims 8 to 14, wherein the organic material comprises one or more of methylene chloride, chloroform, carbon tetrachloride, bromodichloromethane, dibromochloromethane, bromoform, trichloroethylene, tetrachloroethylene, trans-1, 2-dichloroethene, cis-1, 2-dichloroethene, 1, 1-dichloroethene, 1, 2-dichloroethane, 1,1,1-trichloroethane, 1, 1, 2, 2-tetrachloroethane, hexachloroethane, hexachloro-1, 3-butadiene, vinyl chloride, benzene, toluene, ethylbenzene, o-xylene, m-xylene, p-xylene, chlorobenzene, 1, 2-dichlorobenzene, 1, 3-dichlorobenzene, 1, 4-dichlorobenzene, dieldrin, phenol, o-cresol, m-cresol, p-cresol, polychlorinated benzenes, polychlorinated biphenyls, dioxins, chlorine containing dioxins, bromine containing dioxins, brominated benzenes, brominated biphenyls, aromatic ethers and aromatic polyethers.

18. A transmission window for an electron beam accelerator having an anti-corrosion coating on an electron emission surface.

19. A apparatus for irradiating a substrate comprising:
a vacuum chamber including a transmission window;
an electron beam generator within the vacuum chamber; and
an electron beam accelerator tube, within the vacuum chamber, which accelerates and directs electrons from the generator towards and through the transmission window,

said accelerator tube consisting essentially of metal and ceramic components which are fused directly to each other.

20. Apparatus according to claim 19, also comprising an electron beam scanning means.

21. Apparatus according to claim 19, wherein the accelerator tube comprises a plurality of annular metal dynode rings whose centers lie on a straight line and which are joined together through ceramic separators.

22. Apparatus according to claim 19, wherein the dynode rings are composed of titanium or an alloy containing titanium and the separators are composed of alumina.

23. Apparatus according to claim 19, wherein the window comprises a radiation emission surface having a chemically inert anti-corrosion coating.

24. Apparatus according to claim 23, wherein the chemically inert anti-corrosion coating comprises a chemically inert metal, oxide or ceramic.

25. Apparatus according to claim 19, wherein the window is provided by the center section of a foil material whose peripheral portions are held between two mating flanges.

26. Apparatus for irradiating a substrate comprising:
a vacuum chamber including a transmission window;
an electron beam generator within the vacuum chamber; and
an electron beam accelerator tube, within the vacuum chamber, which accelerates and directs electrons from the generator towards and through the transmission window,
the window being generally rectangular in shape when viewed in the direction of the electron beam and convex towards the vacuum chamber with a radius of curvature which is at most twice the width of the rectangle when measured in the absence of a pressure differential across the window; and
wherein a radius of curvature of the window within the rectangle, measured along the width of the rectangle, does not deviate from the average radius of curvature therein by more than 5%.

27. Apparatus for irradiating a fluid material comprising:
(i) a vacuum chamber including a transmission window assembly which comprises a transmission window;
(ii) an electron beam generator within the vacuum chamber; and
(iii) an electron beam accelerator tube, within the vacuum chamber,
which accelerates and directs electrons from the generator towards and through the transmission window,
said transmission window being homogeneous and being formed from foil less than 0.5 mm thick; and
(iv) a housing adjacent to an external surface of the transmission window which comprises:
a wall presenting a surface of similar shape to the external surface of the transmission window but spaced apart therefrom, such that the transmission window and the wall, in combination, define a closed channel flow path for the fluid across the transmission window.

28. Apparatus for irradiating a fluid material according to claim 27, wherein the transmission window:
(i) when viewed in the direction of the electron beam, is generally rectangular in shape and;
(ii) when viewed along the longitudinal axis of the window, is convex towards the vacuum chamber with a radius of curvature which is at most twice the width of the rectangle when measured in the absence of a pressure differential across the window.

29. A apparatus for irradiating a fluid material comprising:
(i) a vacuum chamber including a transmission window assembly which comprises a first transmission window and a second transmission window;
the first transmission window being formed from a foil having a thickness of less than 0.5 mm; and
the second transmission window,
being adjacent to an external surface of the first transmission window,
being formed from a foil having a thickness of less than 0.2 mm, and
being spaced apart from the first transmission window,

(ii) an electron beam generator within the vacuum chamber; and

(iii) an electron beam accelerator tube, within the vacuum chamber,

which accelerates and directs electrons from the generator towards and through the first transmission window and through the second transmission window,

such that the first transmission window and the second transmission window, in combination, define a closed channel flow path for a cooling fluid across at least the first transmission window.

30. Apparatus according to claim 29 wherein the first transmission window:

(i) when viewed in the direction of the electron beam, is generally rectangular in shape and;

(ii) when viewed along the longitudinal axis of the window, is convex towards the vacuum chamber with a radius of curvature which is at most twice the width of the rectangle when measured in the absence of a pressure differential across the window.

31. Apparatus according to claims 27, 28, 29 or 30 also comprising an electron beam scanning means.

32. Apparatus according to claims 27, 28, 29 or 30 wherein the accelerator tube consists essentially of metal and ceramic components which are fused directly to each other.

33. A method for modifying a material by exposure to a beam of accelerated electrons, the method comprising the steps of:

(i) generating an electron beam within a vacuum chamber,

(ii) operating an electron beam accelerator, within the vacuum chamber,

to accelerate and direct a continuous beam of electrons from the generator towards and sequentially through a first transmission window, comprising a foil having a thickness less than 0.5 mm, and through a second transmission window;

the first and second transmission window having facing surfaces that in combination define a closed channel flow path for a coolant fluid;

(iii) directing a cooling fluid along the closed channel flow path thereby defined and at least against the surface of the first window that faces the second window; and

(iv) passing the material to be modified through the beam of electrons emerging from the second window.

34. A method for modifying a material according to claim 33 wherein the first transmission window is homogeneous and:

(i) when viewed in the direction of the electron beam, is generally rectangular in shape and;

(ii) when viewed along the longitudinal axis of the window, is convex towards the vacuum chamber with a radius of curvature which is at most twice the width of the rectangle when measured in the absence of a pressure differential across the window.

35. A method according to claim 33 or 34, wherein the attenuation of the electron beam caused by passing through the first transmission window, the flow path means and the second transmission window is less than 35%.

36. A method for modifying a liquid material by exposure to a beam of accelerated electrons, the method comprising the steps of:

(i) generating an electron beam within a vacuum chamber,

(ii) operating an electron beam accelerator, within the vacuum chamber, to accelerate and direct a continuous beam of electrons from the generator towards and through a transmission window and into a processing chamber having a wall of similar shape to but spaced apart from the transmission window, such that the window and the wall, in combination, define a closed channel flow path for the liquid material through the processing chamber and across the transmission window;

the transmission window having a thickness of less than 0.5 mm; and

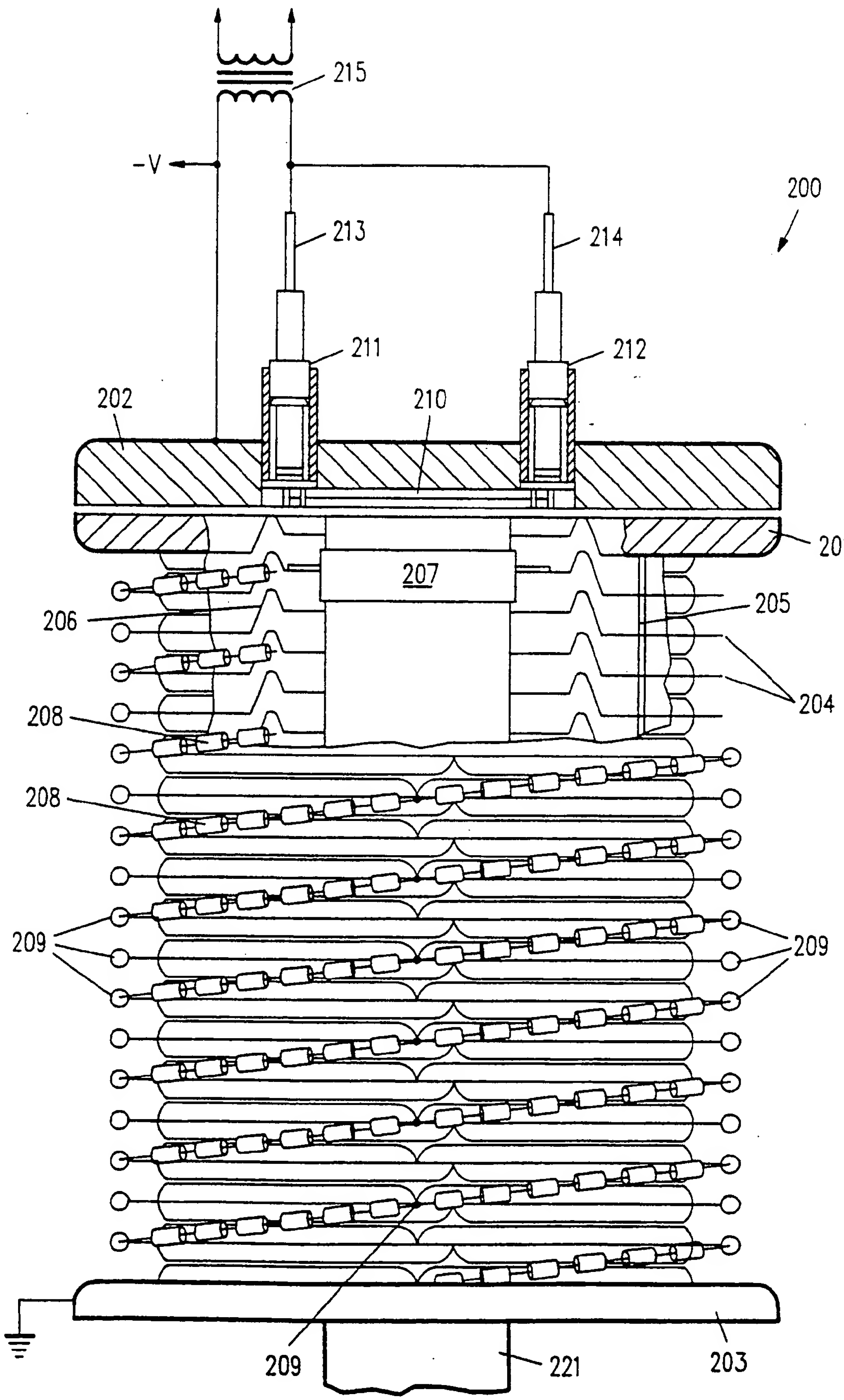
(iii) passing the liquid material along the flow path and through the beam of electrons emerging from the window.

37. A method for modifying a liquid material by exposure to a beam of accelerated electrons, according to claim 36, wherein the transmission window:

(i) when viewed in the direction of the electron beam, is generally rectangular in shape and;
(ii) when viewed along the longitudinal axis of the window, is convex towards the vacuum chamber with a radius of curvature which is at most twice the width of the rectangle when measured in the absence of a pressure differential across the window.

38. A method according to claim 36 or 37, wherein at least 65 % of the energy of the particles exiting the window is absorbed in the liquid material.

39. A method according to claim 34, 35, 36 or 37, wherein the electron beam accelerator comprises an accelerator tube consisting essentially of metal and ceramic components which are fused directly to each other.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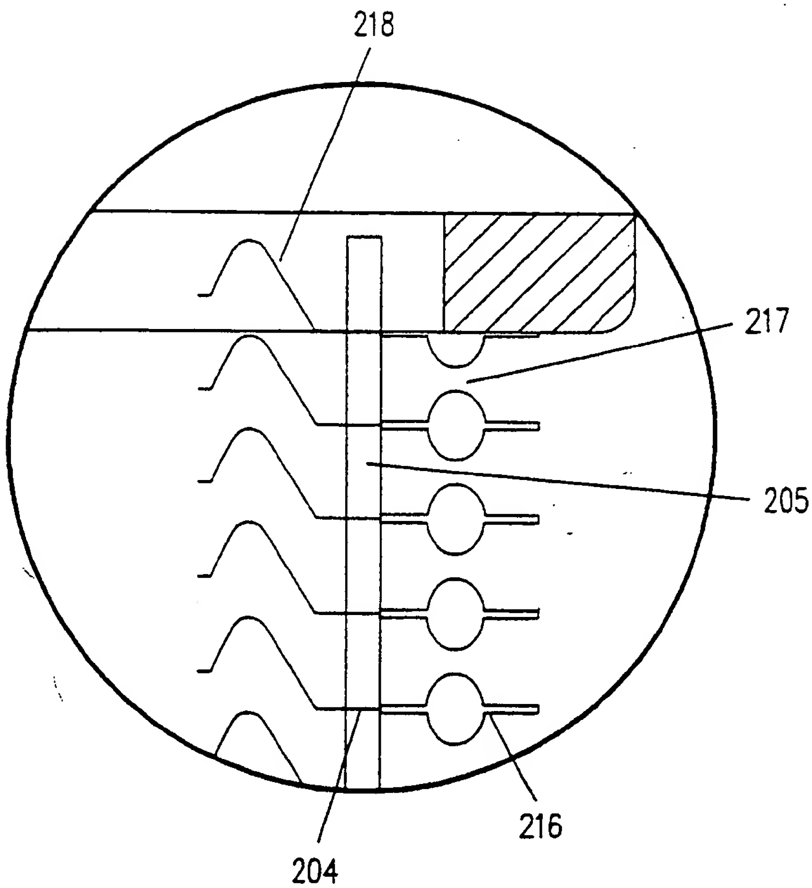
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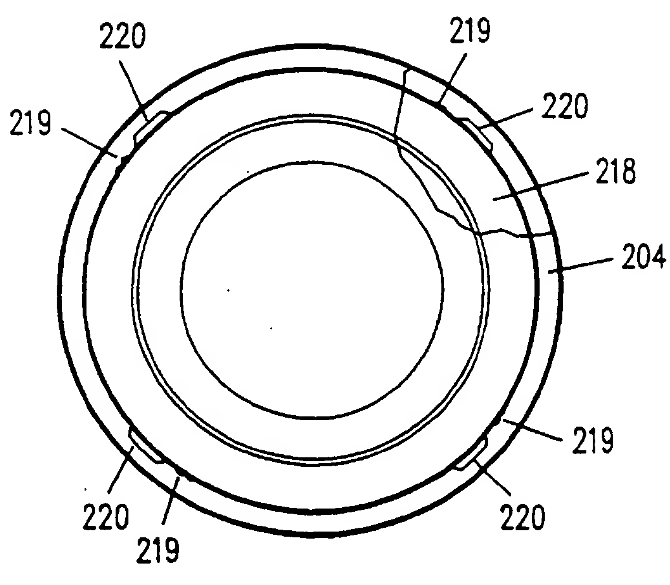
FIG. 2A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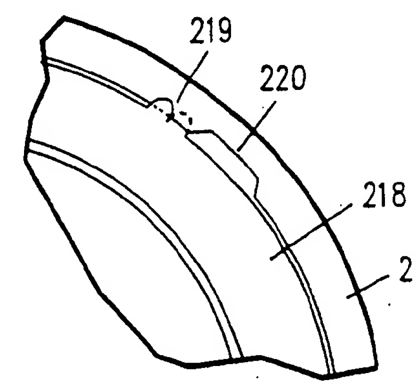
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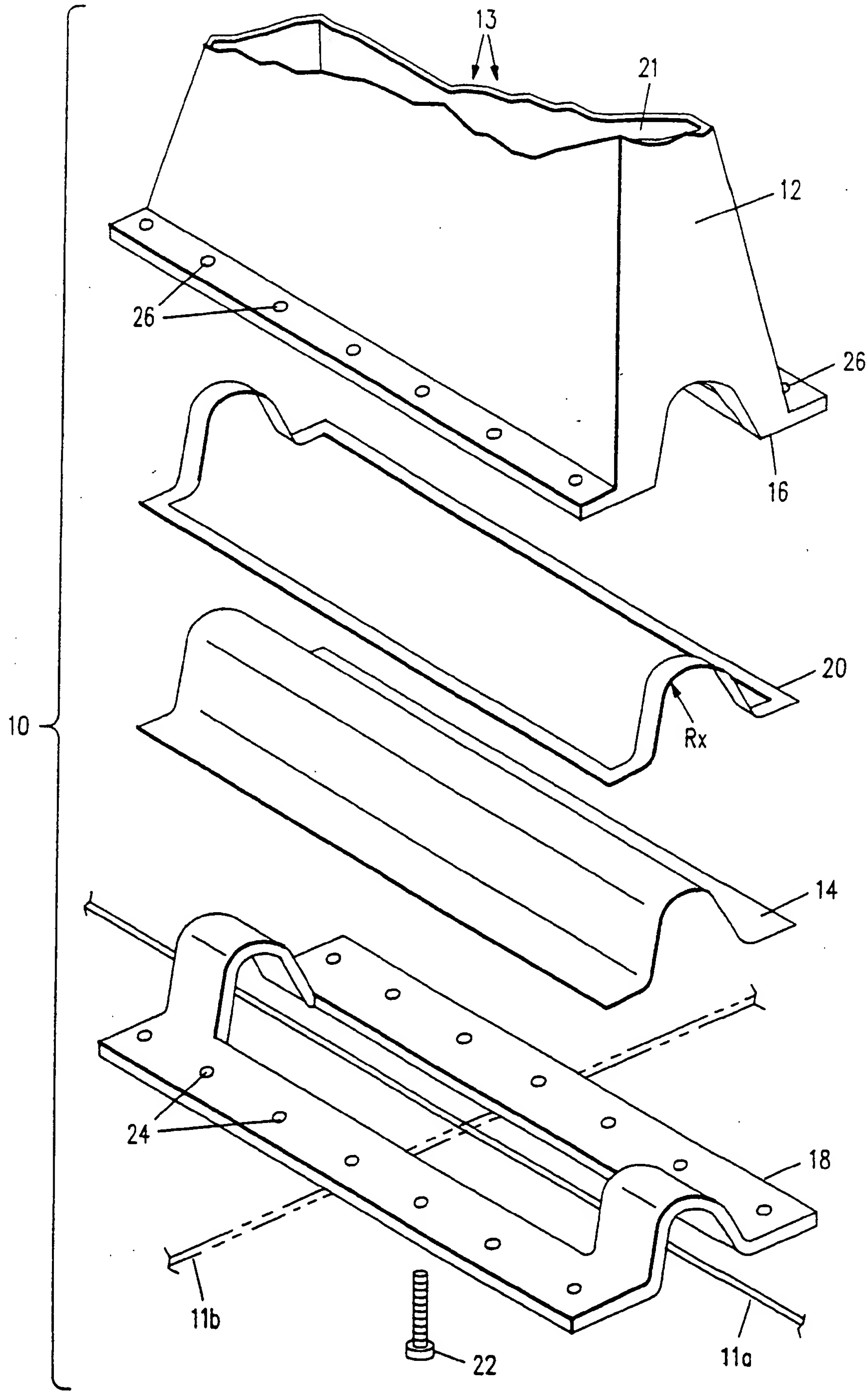
FIG. 2C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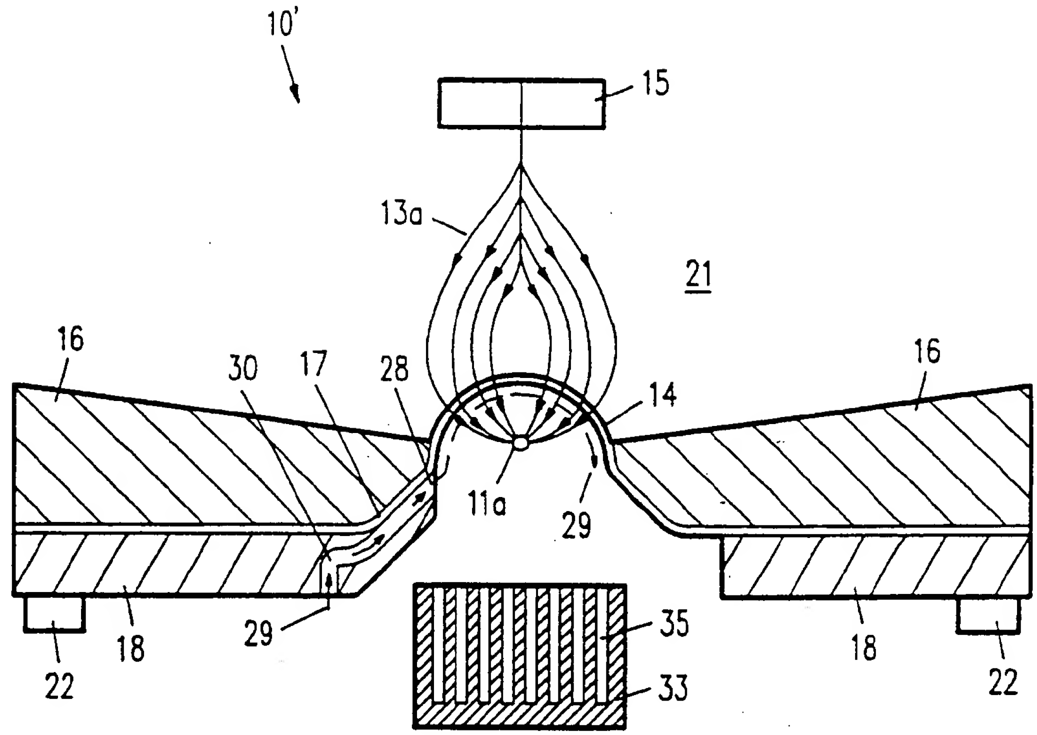
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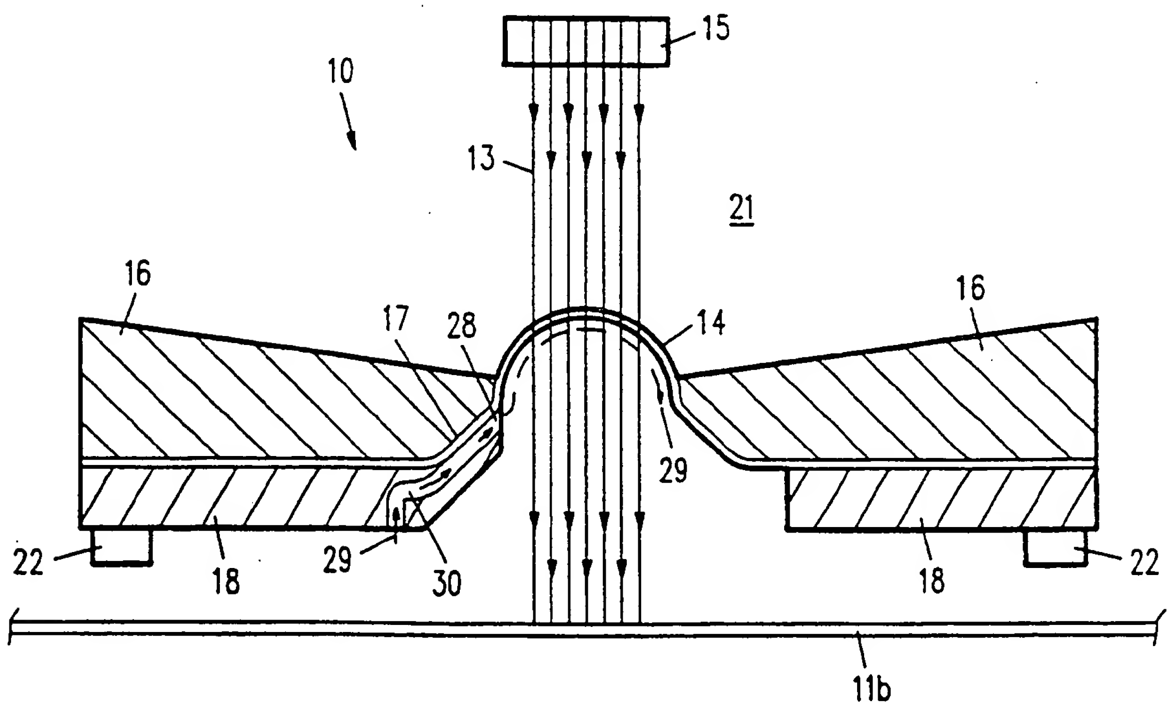
22

FIG. 4


15
10
13
21
16
17
28
14
16
29
22
18
29
30
18
22
11b

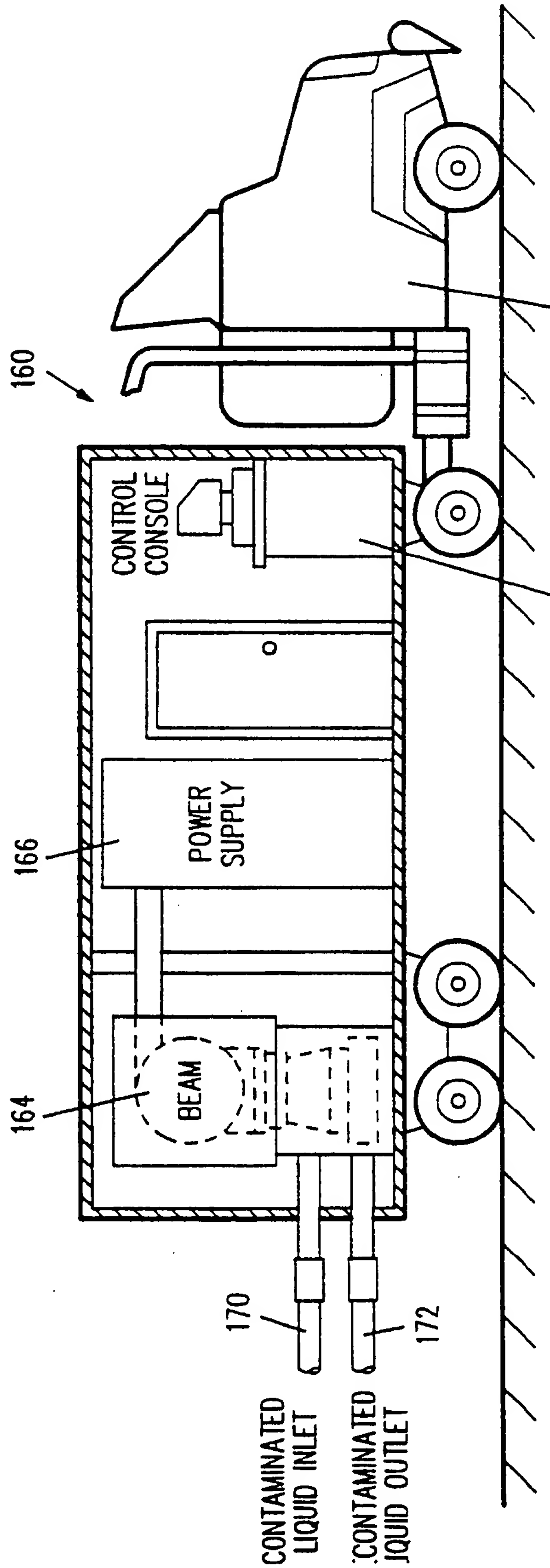

160
162
CONTROL CONSOLE
168
POWER SUPPLY
166
BEAM
164
170
172
CONTAMINATED LIQUID INLET
CONTAMINATED LIQUID OUTLET

FIG. 5

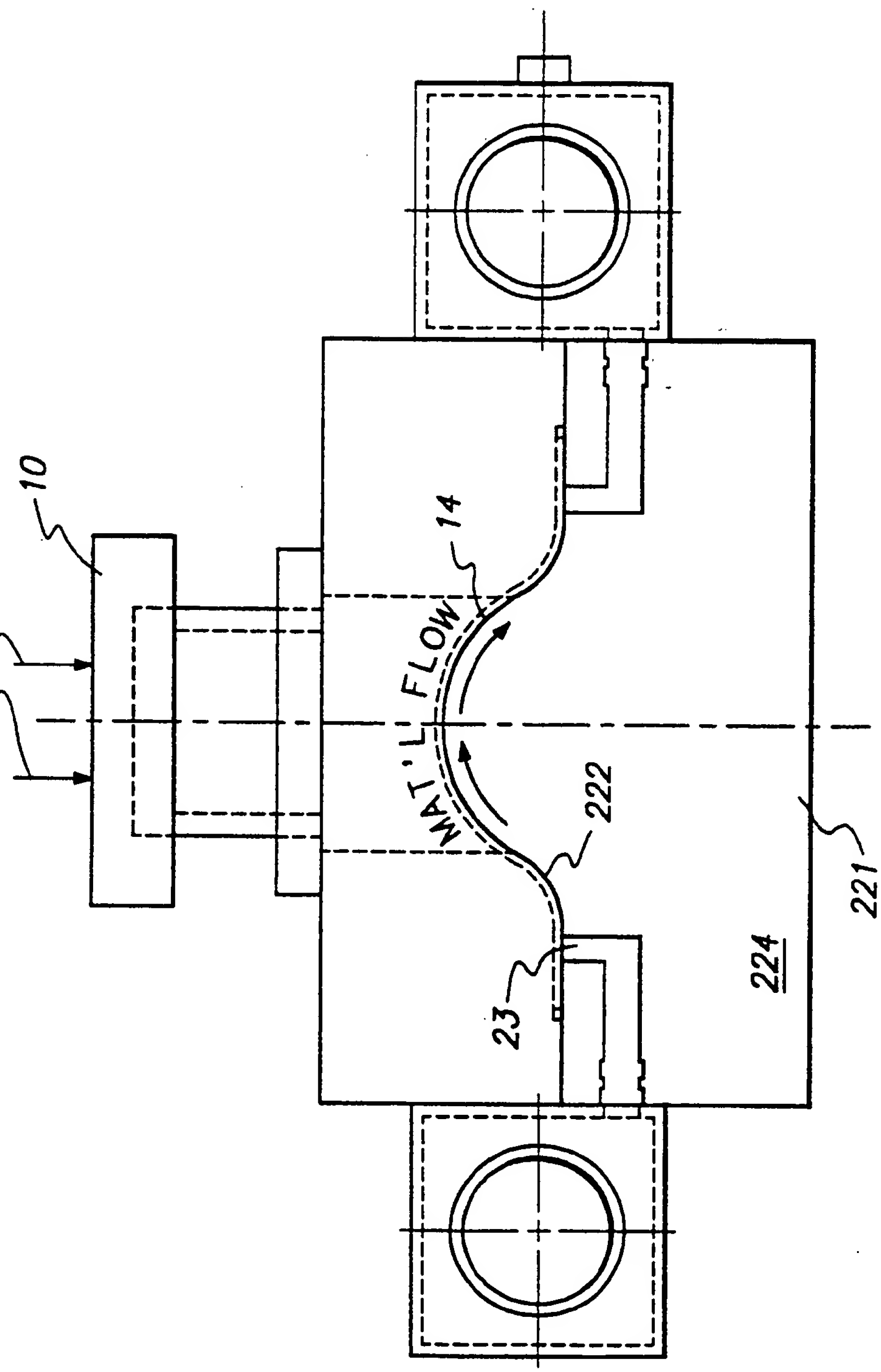


FIG. 6

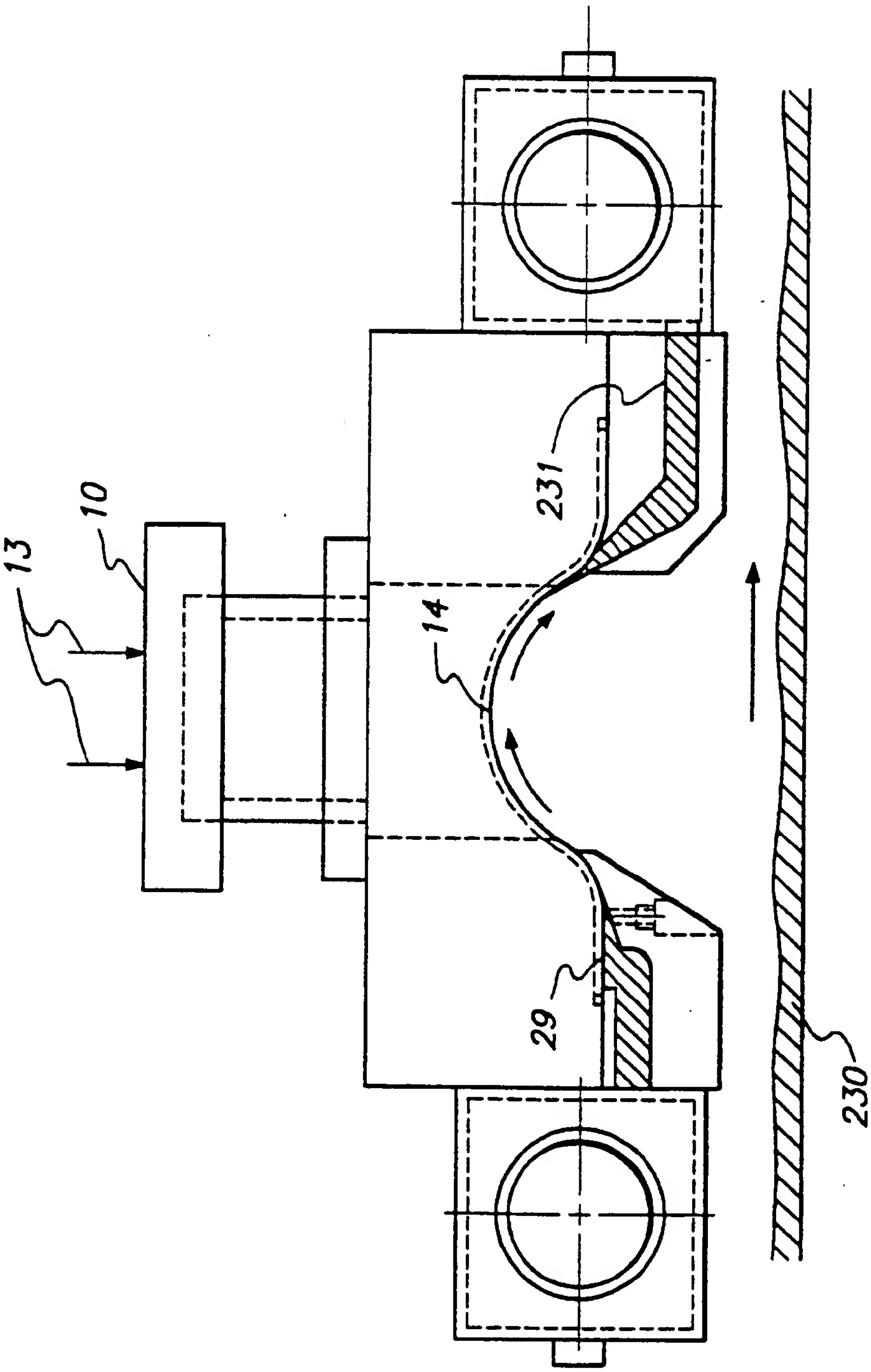


FIG. 7

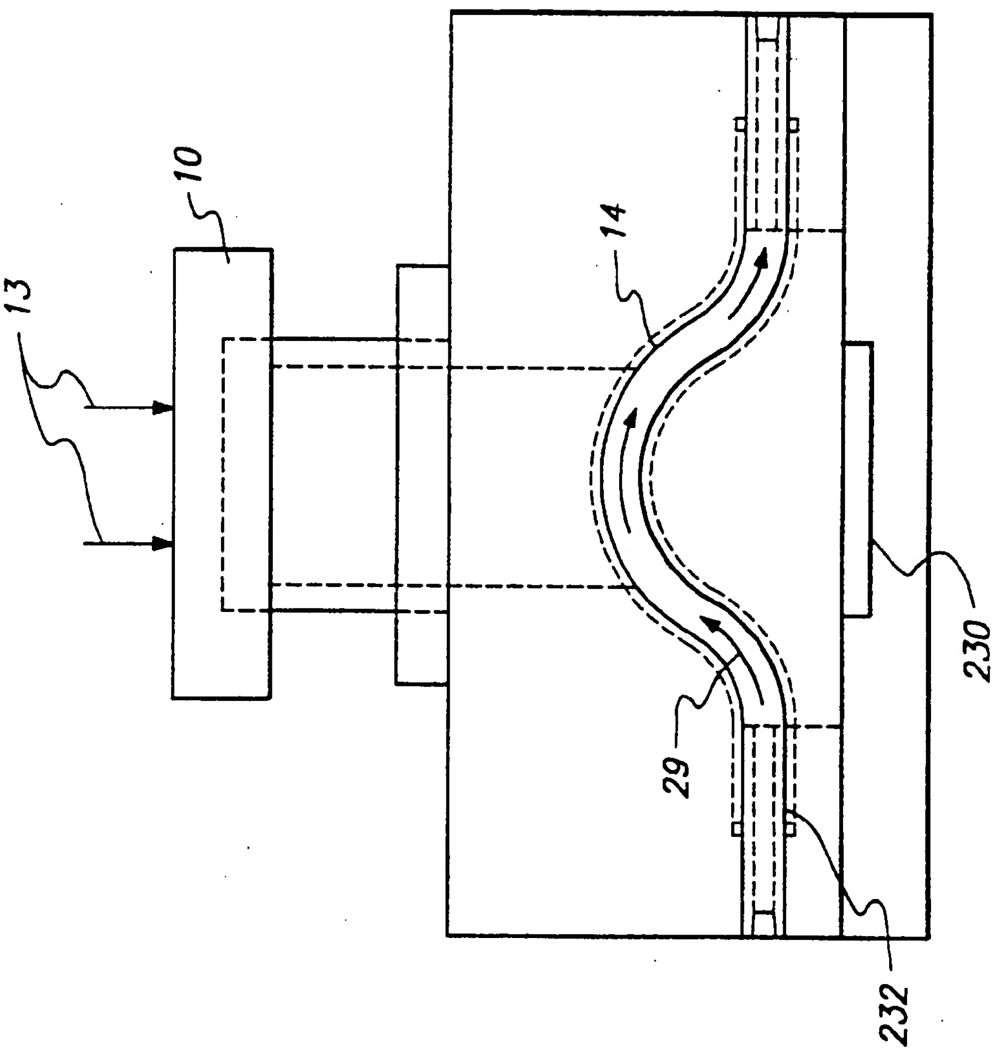


FIG. 8A

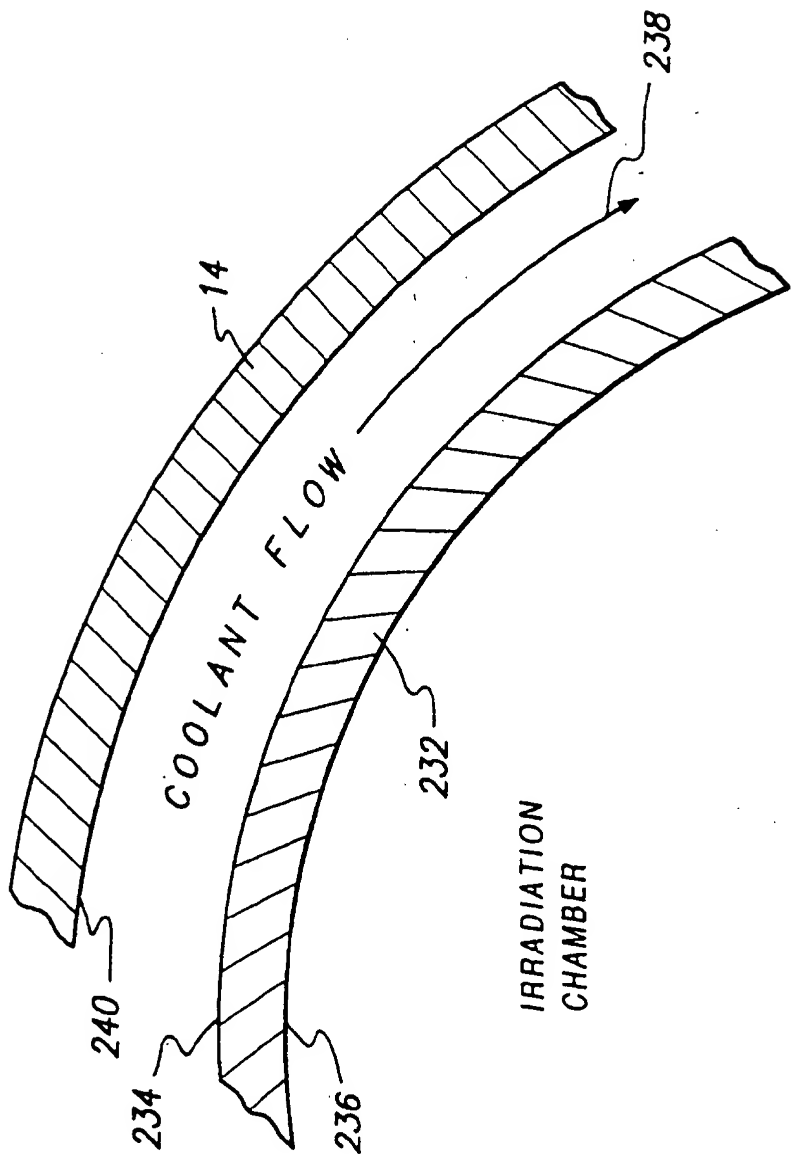


FIG. 8B

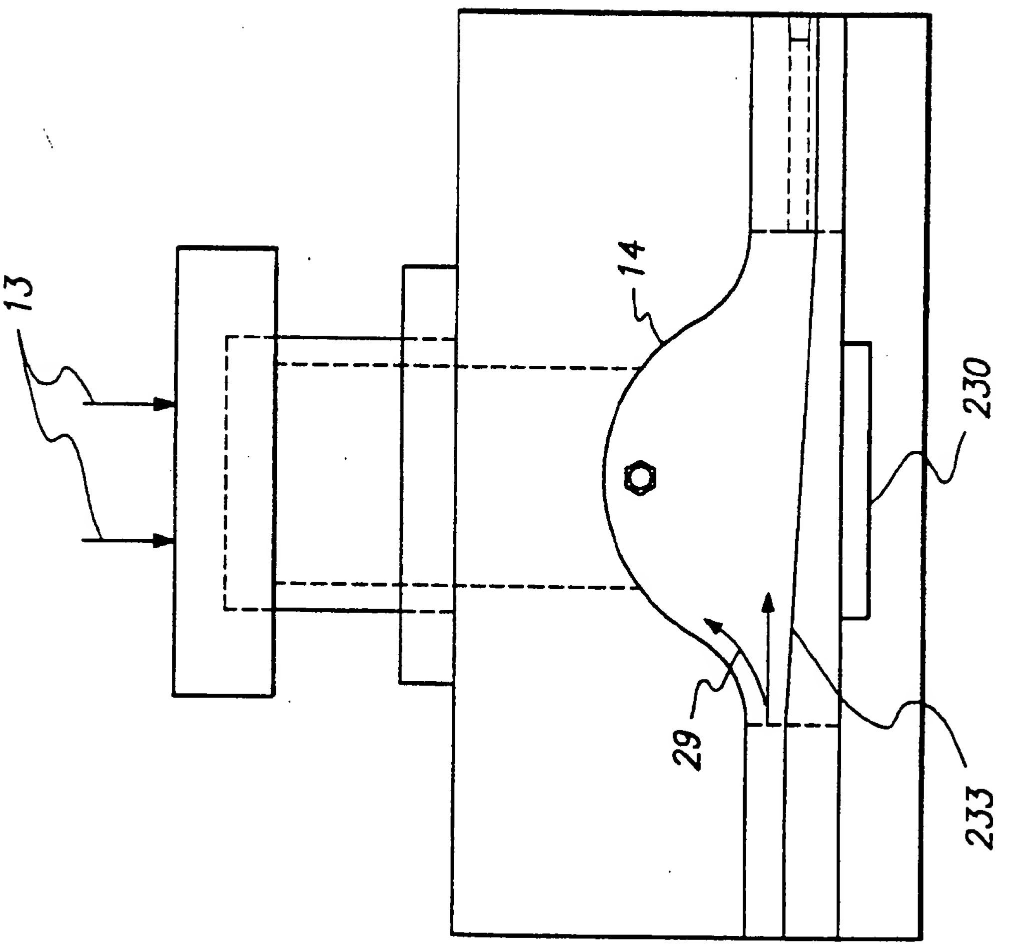


FIG. 9A

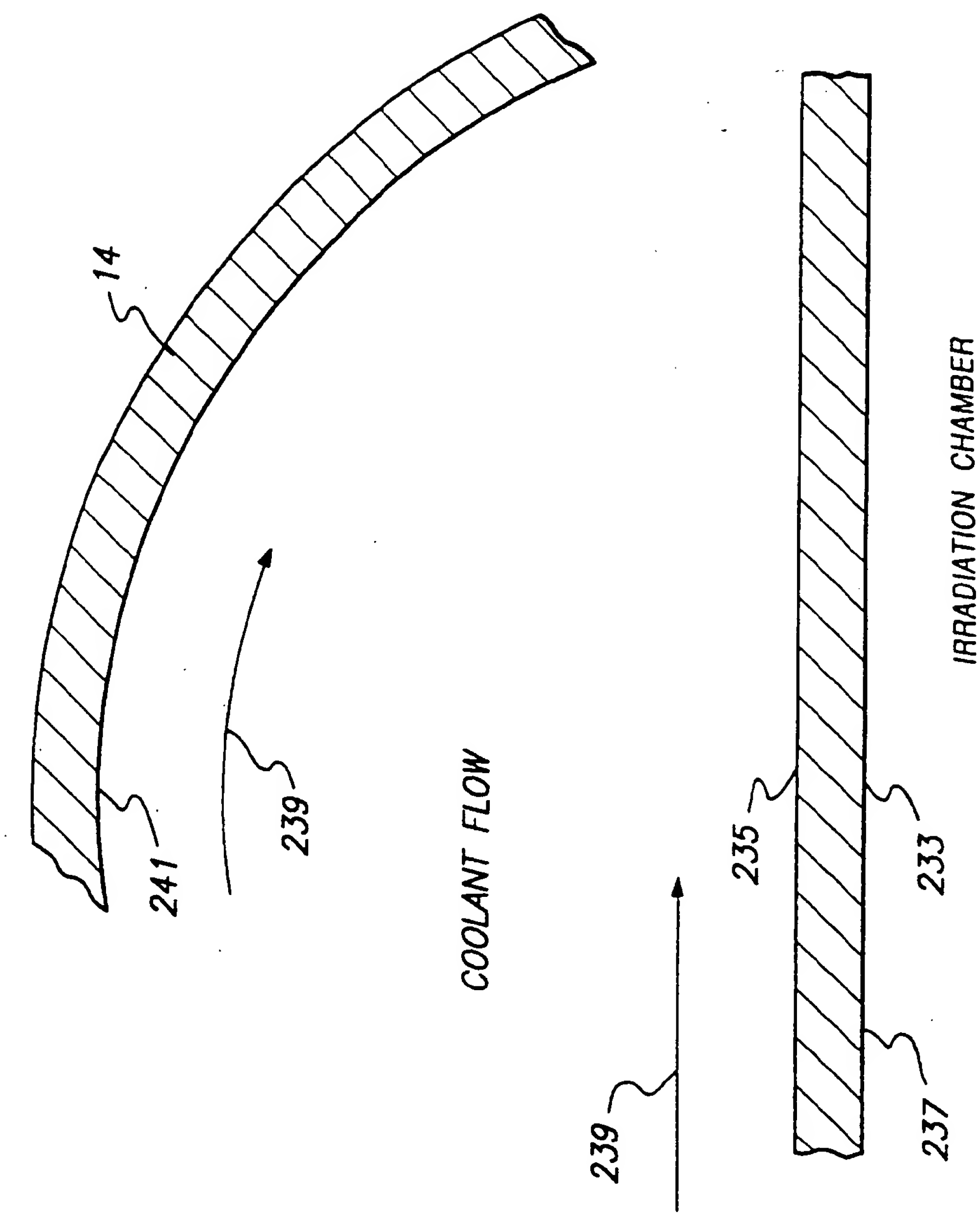


FIG. 9B

INTERNATIONAL SEARCH REPORT

Inte. ›nal Application No
PCT/US 93/08895

A. CLASSIFICATION OF SUBJECT MATTER
IPC 5 G21K5/04 H01J33/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 5 G21K H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO,A,92 03839 (RAYCHEM) 5 March 1992	1,2, 7-14, 26-28, 31,36-38
	see page 1, line 25 - line 30 see page 2, line 24 - line 27 see page 4, line 11 - line 16 see page 5, line 30 - line 33 see page 5, line 35 - page 6, line 1 see page 8, line 16 - line 29 see page 12, line 23 - line 25 see page 13, line 15 - line 17 see page 15, line 4 - line 7 see page 17, line 16 - line 22	
Y	see figures 1,4A	3,4, 19-22, 25,32,39

	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"P" document published prior to the international filing date but later than the priority date claimed

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"&" document member of the same patent family

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Date of the actual completion of the international search	Date of mailing of the international search report
7 December 1993	15. 12. 93
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk	Authorized officer

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 93/08895

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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	see column 3, line 58 - column 4, line 3	
A	see column 10, line 20 - line 41 see column 19, line 30 - line 56 see figure 16 ---	5,23
A	US,A,2 722 620 (GALE ET AL.) 1 November 1955 see column 2, line 58 - column 3, line 4 see column 3, line 21 - line 35 see figures 1-5 ---	1,7,25, 28,30, 34,37
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International Application No
PCT/US 93/08895

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